



OCEAN CURRENTS LESSON PLAN

Motion in the Ocean

Theme

Ocean currents and waves

Links to Overview Essays and Resources Needed for Student Research

<http://oceanservice.noaa.gov/topics/navops/ports/>

<http://oceanservice.noaa.gov/education/kits/currents>

Subject Area

Physical Science/Earth Science

Grade Level

9-12

Focus Question

What causes ocean currents and waves?

Learning Objectives

- Students will identify the primary causes for ocean currents and waves.
- Students will explain how and why ocean currents vary with increasing latitude.
- Students will explain the cause of the Coriolis effect, and how this effect influences ocean currents.
- Students will calculate the magnitude of ocean currents, given data from drifter studies.

Materials Needed

- (Optional) Computers with internet access; if students do not have access to the internet, download copies of materials cited under “Learning Procedure” and provide copies of these materials to each student or student group

Audio/Visual Materials Needed

None

Teaching Time

One 45-minute class period, plus time for student research

Seating Arrangement

Classroom style or groups of 3-4 students

Maximum Number of Students

30

Key Words

Ocean current

Ocean wave

Coriolis effect

Background Information

More than 98% of cargo shipped to and from the United States is transported by water. In addition to accurate information on the geography of coastal areas, safe and efficient navigation of coastal waters requires up-to-the minute information on weather and sea conditions. Since these conditions can vary significantly from place to place and can change dramatically in a short period of time, mariners need accurate real-time information to avoid groundings and collisions. NOAA's Center for Operational Oceanographic Products and Services (CO-OPS) collects and distributes oceanographic observations and predictions to ensure safe, efficient and environmentally sound maritime transportation. The Center:

- provides information on water levels, coastal currents, and tides;
- establishes standards for collecting and processing these data;
- conducts research into new or improved oceanographic observing systems;
- designs software to improve data processing capabilities;
- performs regular data analysis and quality control of data; and
- disseminates this information to the public.

CO-OPS also manages a national network of Physical Oceanographic Real-Time Systems (PORTS®) located in major U.S. harbors. The PORTS® network provides real-time information such as water levels, currents, air gap (the clearance

between the water surface and the bottom of a bridge), weather data, and other oceanographic information to help mariners avoid groundings and collisions. Visit <http://tidesandcurrents.noaa.gov/products> for more information on CO-OPS and their data products. See <http://tidesandcurrents.noaa.gov/programs> for more information on PORTS® and other CO-OPS programs.

While CO-OPS deals mostly with currents along the coast and inside estuaries, other NOAA Program Offices are involved with measuring and understanding currents and circulation patterns in the open ocean. NOAA's National Oceanographic Data Center (NODC) compiles information from the latest ocean current measurement programs that use current meters and drifters. Through the NODC Web site (<http://www.nodc.noaa.gov/General/getdata.html>), you can access a variety of data sets containing information on currents and other oceanographic measurements, such as beach temperatures, coastal buoy data, global temperature and salinity data, and photograph collections. For global current data obtained through satellite remote sensing systems visit NOAA's Ocean Surface Current Analyses - Real Time Web site at <http://www.oscar.noaa.gov/>.

In this lesson, students will explore the relationships between currents, winds, and ocean waves.

Learning Procedure

1.

To prepare for this lesson, review the introductory information on tides and currents at <http://oceanservice.noaa.gov/topics/navops/ports/> and <http://oceanservice.noaa.gov/education/kits/currents>, as well as Parts I and II of the “Currents Worksheets.” If students will not have access to the internet, make enough copies of the Currents Tutorial for each student or student group.

You may also want to review the “Tides and Water Levels” Discovery Kit (<http://oceanservice.noaa.gov/education/kits/tides/>), which offers a tutorial on the complex systems that govern the movement of tides and water levels, a “Roadmap to Resources” that directs you to specific tidal and current data, and lesson plans for students in grades 9–12.

2.

Ask students to comment on the present-day importance of marine navigation. Students should realize that despite the prevalence of air travel and advances in aerospace technology, Earth's oceans are still vital to freight transportation, energy production, and recreation. Discuss the importance of real-time information for safe navigation, and have students brainstorm the types of information that would be useful to a present-day mariner. Tell students that their assignment is to learn some basic facts about "ocean motion," and use this information to solve problems dealing with winds, ocean waves, and currents.

3.

Provide a copy of the "Currents Worksheets" to each student or student group, and have students use the online currents tutorial (or printed copies) to answer worksheet questions.

4.

Lead a discussion of students' answers to worksheet questions. Be sure students understand the relationship between winds, ocean waves, and currents.

The correct answers for Part I are:

- (1) The *velocity* of currents includes speed and direction components.
- (2) Three factors that drive ocean currents are *tidal motion, wind, and differences in water temperature and salinity in different parts of the ocean (thermohaline circulation)*.
- (3) When a coastal tidal current *floods*, it moves toward the land and away from the sea. When a coastal tidal current *ebbs*, it moves toward the sea away from the land.
- (4) As a coastal tidal current moves from ebbing to flooding (and vice versa), there is a period during which there is no current velocity. This period is called *slack water*.
- (5) Tidal currents are most strongly influenced by motions of the *moon*.

- (6) When the moon is at full or new phases, the tidal current velocities are *strong* and are called *spring currents*. When the moon is at first or third quarter phases, tidal current velocities are *weak* and are called *neap currents*.
- (7) *Perigean currents* occur when the moon and Earth are closest to each other. *Apogean currents* occur when the moon and Earth are farthest from each other.
- (8) Wave height is affected by wind *speed*, wind *duration*, and *fetch (the distance over water that the wind blows in a single direction)*.
- (9) Breaking waves are caused by *friction between the seafloor and the water*.
- (10) When a wave reaches a beach or coastline, it releases a burst of energy that generates a current, which runs parallel to the shoreline. This type of current is called a *longshore current*.
- (11) Water flowing in a longshore current can transport beach sediment and cause significant beach erosion through a process known as *longshore drift*.
- (12) A localized current that flows toward the ocean, perpendicular or nearly perpendicular to the shoreline is called a *rip current*.
- (13) Swimmers caught in a rip current can escape by *swimming parallel to the shore instead of towards it, or by letting the current carry them out to sea until the force weakens*.
- (14) A long offshore deposit of sand situated parallel to the coast is called a *barrier island*.
- (15) *Upwelling* occurs when winds blowing across the ocean's surface push water away from an area, causing subsurface water to come up from beneath the surface to replace the diverging surface water. Areas where this occurs are often good for *fishing*, because *subsurface water is typically rich in nutrients, which support the growth of marine algae that provide food for other species*.

- (16) Earth's rotation causes air circulating in the atmosphere to deflect toward the right in the Northern Hemisphere and toward the left in the Southern Hemisphere. This deflection is called *the Coriolis effect*.
- (17) Between 5 degrees North latitude and about 25 degrees North latitude, surface winds generally blow from the northeast to the southwest, and are known as the *trade winds*.
- (18) Between 5 degrees North and 5 degrees South latitude, where the winds are generally sporadic and have little or no velocity. This region is called *the doldrums*.
- (19) Between about 35 degrees North latitude and about 55 degrees North latitude, surface winds generally blow from the west, and are known as *westerlies*.
- (20) Global winds drag on the ocean's surface, causing the water to move in the direction that the wind is blowing and thus create surface ocean currents. Deflection of these currents by Earth's rotation produces spiral currents called *gyres*.
- (21) Each of the major ocean-wide gyres is flanked by a strong and narrow "western boundary current," and a weak and broad "eastern boundary current." The western boundary current of the North Atlantic gyre is called *the Gulf Stream*, and the eastern boundary current of this gyre is known as *the Canary Current*.
- (22) When surface water molecules move by the force of the wind, friction with water molecules below them causes movement of deeper water layers. Deeper layers move more slowly than shallower layers, however, and all layers are deflected by Earth's rotation (to the right in the Northern Hemisphere and to the left in the Southern Hemisphere). These forces create a spiral effect called the *Ekman spiral*.
- (23) Deep-ocean currents below 100 meters are driven by *differences in the water's density*, in a process known as *thermohaline circulation*.

- (24) The global-scale system of deep-ocean currents is sometimes called the *global conveyor belt*.
- (25) Global ocean circulation resulting from deep-ocean currents is vital to the world's food chain because *warm surface waters that have been depleted of nutrients by biological activity are enriched with these nutrients as they circulate as deep- or bottom-water layers*.
- (26) Global ocean circulation resulting from deep-ocean currents could be disrupted by global warming if *increased rainfall in the North Atlantic and melting of glaciers and sea ice reduced the sinking of cold, salty water*.
- (27) Ocean and coastal current velocities are typically measured in *knots*, which is equal to about *1.15* standard (or "statute") miles per hour or about *1.85* kilometers per hour.
- (28) Current measurements made with drifters are termed *Lagrangian* measurements, while measurements of the speed and direction of a fluid at a single point are termed *Eulerian* measurements.

The correct answers for Part II are:

- (1) 3 feet
- (2) Increasing the wind speed by 60 knots would increase the wave height to approximately 12 feet, while increasing the fetch length by 60 nautical miles (nm) would increase the wave height to less than 6 feet.
- (3) A 60 knot wind would have to blow over a fetch of about 9 miles to produce a wave 10 feet high.
- (4) The distance between the points is 524.6 nautical miles. The total time elapsed is 6 days, 10.25 hours = 154.25 hours. So the estimated current speed is:

$$524.6 \text{ nm} \div 154.25 \text{ hr} = 3.40 \text{ nm/hr} = 3.40 \text{ knots}$$

The estimated direction of the current is northeast.

- (5) The distance between the points is 1,443.68 kilometers = 1.444×10^8 centimeters. The total time elapsed is 14 days, 2.92 hours = 338.92 hours = 1.220×10^6 seconds. So the estimated current speed is

$$1.444 \times 10^8 \text{ cm} \div 1.220 \times 10^6 \text{ sec} = 118.4 \text{ cm/sec}$$

The estimated direction of the current is slightly east of due south.

- (6) Since the latitude at the equator is zero, the formula for Coriolis acceleration suggests that the magnitude of this acceleration at the equator is zero.
- (7) The latitude of Tijuana is about 32.5° N. A velocity of 10 meters/second is equal to 1,000 centimeters/second. So, the magnitude of the Coriolis acceleration is

$$(\sin 32.5^\circ \cdot 1.5 \times 10^{-4} \cdot 1,000) \text{ cm/sec}^2$$

$$= 0.537 \cdot 1.5 \times 10^{-4} \cdot 1,000 = 0.081 \text{ cm/sec}^2$$

The effect is very small.

- (8) Even though the effect of Coriolis acceleration on soccer balls, walking humans, etc. is practically negligible, when it acts on very large masses over very long distances, the acceleration becomes significant.

The Bridge Connection

<http://www.vims.edu/bridge/> – In the “Site Navigation” menu on the left, click on “Ocean Science Topics,” then “Physics,” then one of the headings at the top of the page for links and resources about tides, waves, and currents.

The Me Connection

Have students write a short essay on how the Coriolis force affects them personally, even though it only is significant at very large scales.

Extensions

1. Visit the “Tides and Water Levels” Discovery Kit (<http://oceanservice.noaa.gov/education/kits/tides/>) for additional resources and lesson plans.
2. Visit <http://www.usm.maine.edu/maps/lessons/nr10.htm> and <http://www.usm.maine.edu/maps/lessons/nr11.htm> for additional lesson plans and activities about currents from the University of Southern Maine’s Osher Map Library.
3. Visit Multimedia Learning Objects at <http://www.learningdemo.com/noaa/>. Click on the links to Lessons 8 and 9 for interactive multimedia presentations and Learning Activities on Ocean Currents and Ocean Waves, including an activity involving landing safely on an aircraft carrier by allowing for the Coriolis Effect.

Resources

<http://oceanexplorer.noaa.gov/explorations/03edge/background/educational/coriolis.pdf> – Lesson on the Coriolis force from NOAA’s Ocean Explorer program, including “the Dishpan Analogy” explanation for this effect

<http://oceanservice.noaa.gov/education/kits/tides/> – NOAA’s “Tides and Water Levels” Discovery Kit

<http://tidesandcurrents.noaa.gov> – NOAA’s Center for Operational Oceanographic Products and Services (CO-OPS) Web page, with links to data and information about tides, water levels, currents, predictions, weather observations, forecasts, and harmonic constituents

<http://www.usm.maine.edu/maps/lessons/nr10.htm> and <http://www.usm.maine.edu/maps/lessons/nr11.htm> – Lesson plans and activities about currents from the University of Southern Maine’s Osher Map Library

<http://www.eeb.ucla.edu/test/faculty/nezlin/PhysicalOceanography.htm> — Online tutorial with additional details about ocean currents

National Science Education Standards**Content Standard A: Science as Inquiry**

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

Content Standard B: Physical Science

- Motions and forces

Content Standard D: Earth and Space Science

- Energy in the Earth system

Content Standard E: Science and Technology

- Abilities of technological design
- Understandings about science and technology

Content Standard F: Science in Personal and Social Perspectives

- Natural resources
- Environmental quality
- Natural and human-induced hazards
- Science and technology in local, national, and global challenges



TIDES AND CURRENTS WORKSHEET

Part I: Review Questions for “Currents” Tutorial

(<http://oceanservice.noaa.gov/education/kits/currents>)

1. The _____ of currents includes speed and direction components.
2. Three factors that drive ocean currents are _____.
3. When a coastal tidal current _____ it moves toward the land and away from the sea. When a coastal tidal current _____ it moves toward the sea away from the land.
4. As a coastal tidal current moves from ebbing to flooding (and vice versa), there is a period during which there is no current velocity. This period is called _____.
5. Tidal currents are most strongly influenced by motions of the _____.
6. When the moon is at full or new phases, the tidal current velocities are _____ and are called _____. When the moon is at first or third quarter phases, tidal current velocities are _____ and are called _____.
7. “_____ currents” occur when the moon and Earth are closest to each other. “_____ currents” occur when the moon and Earth are farthest from each other.
8. Wave height is affected by wind _____, wind _____, and _____.
9. Breaking waves are caused by _____.
10. When a wave reaches a beach or coastline, it releases a burst of energy that generates a current, which runs parallel to the shoreline. This type of current is called a _____.

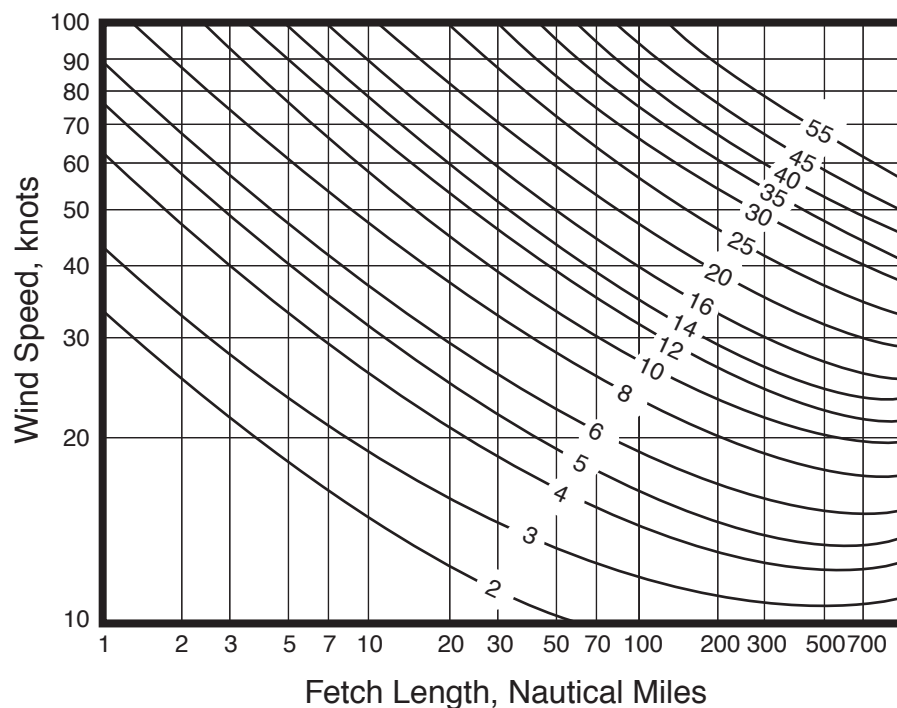
11. Water flowing in a longshore current can transport beach sediment and cause significant beach erosion through a process known as _____.
12. A localized current that flows toward the ocean, perpendicular or nearly perpendicular to the shoreline is called a _____.
13. Swimmers caught in a rip current can escape by _____.
14. A long offshore deposit of sand situated parallel to the coast is called a _____.
15. _____ occurs when winds blowing across the ocean's surface push water away from an area, causing subsurface water to come up from beneath the surface to replace the diverging surface water. Areas where this occurs are often good for _____, because _____.
16. Earth's rotation causes air circulating in the atmosphere to deflect toward the right in the Northern Hemisphere and toward the left in the Southern Hemisphere. This deflection is called _____.
17. Between 5 degrees North latitude and about 25 degrees North latitude, surface winds generally blow from the northeast to the southwest, and are known as the _____.
18. Between 5 degrees North and 5 degrees South latitude, where the winds are generally sporadic and have little or no velocity. This region is called _____.
19. Between about 35 degrees North latitude and about 55 degrees North latitude, surface winds generally blow from the west, and are known as _____.
20. Global winds drag on the ocean's surface, causing the water to move in the direction that the wind is blowing and thus create surface ocean currents. Deflection of these currents by Earth's rotation produces spiral currents called _____.

21. Each of the major ocean-wide gyres is flanked by a strong and narrow “western boundary current,” and a weak and broad “eastern boundary current.” The western boundary current of the North Atlantic gyre is called _____, and the eastern boundary current of this gyre is known as _____.
22. When surface water molecules move by the force of the wind, friction with water molecules below them causes movement of deeper water layers. Deeper layers move more slowly than shallower layers, however, and all layers are deflected by Earth’s rotation (to the right in the Northern Hemisphere and to the left in the Southern Hemisphere). These forces create a spiral effect called _____.
23. Deep-ocean currents below 100 meters are driven by _____, in a process known as _____.
24. The global-scale system of deep-ocean currents is sometimes called the _____.
25. Global ocean circulation resulting from deep-ocean currents is vital to the world’s food chain because _____.
26. Global ocean circulation resulting from deep-ocean currents could be disrupted by global warming if _____.
27. Ocean and coastal current velocities are typically are measured in _____, which is equal to about _____ standard (or “statute”) miles per hour or about _____ kilometers per hour.
28. Current measurements made with drifters are termed “_____ measurements,” while measurements of the speed and direction of a fluid at a single point are termed “_____ measurements.”

Part II. Problems on Winds, Waves, and Currents

1. Surface ocean waves are produced by winds. The height of these waves depends upon wind speed, the length of time the wind blows (duration) and the distance over which the wind blows (fetch). In 1952, Charles Bretschneider created a diagram that describes the relationship between these parameters and provides an easy way to predict the height of a wave produced by specific wind conditions. Figure 1 is an example of this kind of diagram (usually called a “Sverdrup-Munk-Bretschneider nomogram”). The y-axis describes Wind Speed; the x-axis describes Fetch Length; solid curved lines in the middle of the diagram show the Wave Height in feet (most Sverdrup-Munk-Bretschneider nomograms also include lines showing wave period and wind duration; these have been omitted from Figure 1 for clarity). When using the nomogram, be sure to match these lines with the correct labels!

Figure 1: Sverdrup-Munk-Bretschneider Nomogram



1. If a wind blows over a 10 nautical mile fetch at 21 knots, what would the resulting wave height be?
2. What would cause the larger increase in wave height for conditions in the preceding question: increasing the wind speed by 60 knots or increasing the fetch length by 60 nautical miles?
3. What would be the minimum fetch over which a 60 knot wind would have to blow to produce a wave 10 feet high?
4. There are a variety of ways to measure the velocity of a current. One of the oldest and simplest methods is to use a "drifter," which can be any floating object (an ideal drifter is one that is not affected by wind; glass bottles partially filled with sand are a traditional type of drifter). To measure current velocity, an observer places the drifter into the water, measures the amount of time the drifter takes to move a known distance, and notes the direction of the drifter's motion (since velocity is a vector quantity, and has dimensions of direction as well as speed). Next, the observer finds the speed of the current by dividing the distance the drifter traveled by the time it took to travel that distance. The speed of the drifter combined with the direction in which it moved is the current's velocity.

In early oceanographic studies, drifters were released into the open ocean with an attached tag that asked any person who recovered the drifter to return the tag along with information about the date and location in which the drifter was recovered. Some of these drifters were actually found and their tags returned, providing the basis for estimates of ocean currents.

Suppose a drifter is released near Charleston, SC from a research vessel whose position is $32^{\circ}23'15''$ North latitude, $79^{\circ}12'33''$ West longitude, at 0915 eastern standard time (EST) on May 11, 2004. A sailing yacht recovers the drifter at 1930 EST on May 17, 2004 in position $39^{\circ}56'23''$ North latitude, $73^{\circ}44'35''$ West longitude. What is the estimated velocity of the current that transported this drifter? In this case, it is sufficient to describe the direction component

of the velocity vector as north, northeast, east, southeast, south, southwest, west, or northwest. State the speed component of the vector in knots (nautical miles per hour).

[Hint: You can use the calculator at <http://www.wcrl.ars.usda.gov/cec/java/lat-long.htm> to find the distance between two points whose latitude and longitude are known.]

If you would like to have a map of the area covered by the drifter, visit the Marine Geoscience Data System Web site (<http://www.marine-geo.org/maps>). Enter the latitude and longitude boundaries for the area you want the map to cover, then click on the “Map” button. In this case you would enter 40° as the northern boundary; -80° as the western boundary (note that longitudes west of the prime meridian are assigned a negative value, while longitudes east of the prime meridian are positive); -73° as the eastern boundary; and 32° as the southern boundary. The map will show the elevation (or depth) of Earth’s surface in the included area. You can download the map using the “Save Image As . . .” function of your Web browser.

5. Suppose an amateur oceanographer in Oregon releases a drift bottle from position 46°13'56" North latitude, 125°47'12" West longitude, at 1140 Pacific standard time (PST) on August 6, 2005. At 1435 PST on August 20, 2005, the bottle is found floating between the islands of Santa Cruz and Santa Rosa in Channel Islands National Park at 34°00'23" North latitude, 120°00'10" West longitude. Estimate the velocity of the current that transported this drifter. Describe the direction component of the velocity vector as north, northeast, east, southeast, south, southwest, west, or northwest, and state the speed component of the vector in centimeters per second.

You can use the Marine Geoscience Data System Web site (<http://www.marine-geo.org/maps>) to generate a map as described above. Enter 47° as the northern boundary; -126° as the western boundary; -120° as the eastern boundary; and 34° as the southern boundary.

6. The deflection of moving objects caused by Earth's rotation is called the Coriolis effect. Acceleration due to the Coriolis effect always acts at right angles to the direction of the velocity vector, and has a magnitude of

$$(2 \cdot w \cdot v \cdot \sin f) \text{ cm/sec}^2$$

where w is the angular velocity of Earth, v is the velocity of the moving object, and f is the latitude in degrees.

Since the angular velocity of Earth is about 7.29×10^{-5} radians/sec, acceleration due to the Coriolis effect is about

$$(1.5 \times 10^{-4} \cdot v \cdot \sin f) \text{ cm/sec}^2$$

(note that radians have no units).

What does this equation suggest about the magnitude of the Coriolis acceleration at the equator?

7. Suppose a soccer player in Tijuana, Mexico kicks a soccer ball with a velocity of 10 meters per second. What is the effect of the Coriolis acceleration on the ball?
8. Given the results of the preceding question, why is Coriolis acceleration significant to the circulation in the atmosphere and ocean?